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PATENT APPLICATION

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CASE Thompson 6

TITLE Bi-directional Optical Transmission Using Dual Channel Bands

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

NEW APPLICATION UNDER 37 CFR § 1.53(b)

Enclosed are the following papers relating to the above-named application for patent:

Specification (19 pgs.)
[1] Formal Sheets of drawing(s)
[1] Assignment(s) with Cover Sheet
Declaration and Power of Attorney
Information Disclosure Statement

CLAIMS AS FILED				
	NO. FILED	NO. EXTRA	RATE	CALCULATIONS
Total Claims	22 - 20 =	2	x \$18 =	\$36
Independent Claims	3 - 3 =	0	x \$78 =	\$0
Multiple Dependent Claims, if applicable			+ \$260 =	\$0
Basic Fee				\$690
			TOTAL FEE	\$726

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Respectfully,

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BI-DIRECTIONAL OPTICAL TRANSMISSION USING DUAL CHANNEL BANDS

FIELD OF THE INVENTION

The present invention relates generally to optical communications systems and more particularly to optical communications systems providing communications over a single optical fiber.

5 BACKGROUND OF THE INVENTION

Bi-directional optical communications systems of the prior art which are capable of two-way transmission over a single optical fiber typically employ wavelength division multiplexing to separate and distribute the communications traffic over a number of distinct wavelengths. One prior art method of single fiber bi-directional optical
10 communications employs wavelength interleaving, where wavelengths traveling in a first direction are interleaved with wavelengths traveling in a second direction. For instance, incremental wavelengths designated as λ_1 , λ_3 , λ_5 , etc. are set up to travel in the first direction, whereas within the same spectral band, wavelengths λ_2 , λ_4 , λ_6 , etc. travel in the second direction.

15 Another form of bi-directional communication interleaves multiple sub-bands or blocks of related wavelengths. For example, wavelengths λ_{1-4} may be set up to travel in a first direction, wavelengths λ_{5-8} to travel in a second direction, wavelengths λ_{9-12} to travel in the first direction, wavelengths λ_{13-16} to travel in the second direction and so on. In each of the above cases, all of the wavelengths that are utilized are found within the same
20 frequency band, for example, the C-band. Each of the methodologies employs multiple filters in each sub-band in order to process the multiple wavelengths. A consequence is that the presence of the multiple filters produces relatively large overall signal losses. A further consequence is that the loss in the multiple filters can be optimized for only one sub-band in each direction. Accordingly, there is a need for a system that provides
25 decreased signal losses over a wider band of wavelengths/frequencies.

SUMMARY OF THE INVENTION

A bi-directional optical transmission system according to the present invention provides transport of x optical channels over n nodes. The system supports two-way transport of the x channels over a single fiber connecting each of the nodes in sequence. The system is advantageous in that only two optical transmission bands are utilized in order to achieve minimal loss in the separation of signals in the two bands. The two directions of optical transmission within the system have a spectral (wavelength/frequency) separation, in addition to directional separation. The use of only two bands permits the utilization of low-loss wide band thin film optical filters to combine and separate the signals at each node. Further processing of the signals takes place in unidirectional components, e.g., multiplexers, demultiplexers and amplifiers, as required. An alternating arrangement of the optical filters in the two separate bands is chosen to maximize the optical performance of the overall system and significantly reduce insertion losses.

In one exemplary embodiment of the present invention, at each intermediate node in the system, a transmission filter for the first band of optical signals is used between the output of an optical amplifier for the first band and the bi-directional fiber. A reflection port of this filter is used to carry oppositely directed signals of the second band from the bi-directional fiber to an optical amplifier for the second band. An optical transmission filter for the second optical band is also used at each intermediate node between the output of an optical amplifier for the second band and the bi-directional fiber. The reflection port of the second band filter is used to carry the input signal of the first band from the bi-directional fibers to the optical amplifier for the first band. End nodes in the system include only an appropriate one of the transmission filters. The alternate arrangement of filters simultaneously provides for optimal signal performance for both directions of transmission at every node in the system while at the same time minimizing insertion losses from filtering components.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present invention may be obtained from consideration of the following detailed description of the invention in conjunction with the drawing, with like elements referenced with like references, in which:

FIG. 1 is an exemplary embodiment of a bi-directional optical transmission system in accordance with the present invention.

DETAILED DESCRIPTION

Referring to Fig. 1, there is shown one exemplary embodiment of a bi-directional fiber transmission system 10 in accordance with the present invention. The system 10 provides transport of x channels between a first end node 12 and a second end node 14 at different locations. An intermediate node, or a repeater node 16, is shown coupled between the first and second end node 12, 14. It would be understood that any number of intermediate nodes can be coupled in the signal path between the two end nodes in order to maintain appropriate optical transmission levels. Accordingly, a complete bi-directional fiber transmission system includes a total of n nodes. It would also be understood that intermediate nodes may be more than just repeater type nodes and can include pairs of end nodes as well as optical add and drop nodes. In principal, end nodes 12, 14 could be located in the same office and the traffic (structure) connected between them so as to form a complete ring system and not just a simple linear connected chain of nodes. Optical fiber 18 for carrying the bi-directional signals transmitted through the system is coupled between each of the nodes.

The present invention is advantageous in that only two transmission bands, for example, the "C" band in one direction and the "L" band in the other direction, are utilized in order to achieve minimal loss in the separation of signals in the two bands. As is known by those skilled in the art, the C-band generally includes wavelengths in the range of 1530 to 1563 nm and the L-band generally includes wavelengths in the range of 1573 to 1610 nm. The two directions of optical transmission on the fiber 18 between the end nodes 12, 14 have a spectral (wavelength/frequency) separation, in addition to directional separation. The use of only two bands permits the utilization of low-loss wide

band thin film optical filters to combine and separate the signals at each node. Further processing of the signals takes place in unidirectional components, e.g., multiplexers, demultiplexers and amplifiers, as required. As shown in Fig. 1, the signals in the C-band propagate from the first end node 12 to the second end node 14, while signals in the L-band propagate from the second end node 14 to the first end node 12.

At the first end node 12, a given number, x , of optical translator units 20 receive incoming signals from the x corresponding wavelength channels. The optical translator units 20 (OTUs) translate the incoming wavelengths (typically 1310 nm) to an appropriate wavelength in the C-band (typically in the range of 1530nm to 1563nm). The OTUs 20 are coupled to an optical multiplexer 22 unit which is in turn coupled to an optical amplifier unit 24. These C-band signals are spectrally combined in the optical multiplexer 22 and then amplified via the optical amplifier 24. The output of the optical amplifier 24 couples to an input port 26 of a combiner/separator unit 30 designated in the figure as "COMSEP". As its name implies, the COMSEP 30 combines optical signals traveling in a first direction and separates optical signals traveling in the opposite direction. As shown, the COMSEP includes a single band input port 26, a single band output port 28 and a bi-directional input/output port 32. The single band ports 26, 28 act as inputs and outputs for optical signals of the predefined signal bands traveling in a single direction. In addition, although referred to as single band input and output ports it would be understood that these terms are not meant to be limiting with regard to the specific construction of the ports themselves. That is, the ports are referenced in such a manner so as to provide clarification as to the predominate direction of signal flow throughout the system 10. Internally, the COMSEP unit 30 of the first end node 12 includes a C-band transmission filter 34. A COMSEP containing a C-band transmission filter may be generally referenced as a "C-band COMSEP" in later portions of the document. As will be explained, the C-band filter 34 enables the C-band signals to be transmitted to the bi-directional input/output port 32 of the COMSEP 30 with low insertion loss.

As would be understood, both C-band and L-band signal bands are present at the bi-directional input/output port 32 of the COMSEP 30 and within the fiber 18 connecting between each of the nodes. The C-band signals propagate from the first end node 12

through the intermediate nodes 16 to the second end node 14 on this common fiber 18.

At the first end node 12, incoming L-band signals arriving on the bi-directional input/output port 32 are reflected from the C-band filter 34 of the COMSEP 30 and are output through the single band output port 28. The single band output port 28 of the first COMSEP 30 couples to an L-band optical amplifier 36 which in turn couples to an optical demultiplexer (DEMUX) 38. The L-band signals are amplified within the optical amplifier 36 and then spectrally separated in the demultiplexer 38. In converse functionality to the C-band OTUs, L-band optical translator units 40 couple to the outputs of the optical demultiplexer 28 for converting the L- band signals back to a nominal wavelength (typically 1310nm).

A first repeater node 16 couples to the bi-directional input/output port 32 of the first end node 12. As shown, the repeater node 16 includes two combiner/seperator units (COMSEPs) 42, 44 and two optical amplifiers 46, 48 (one each for the L-band and one each for the C-band). As with the COMSEP 30 of the first end node 12, each COMSEP 42, 44 of a repeater node 16 includes a bi-directional input/output port 50, 51 a single band input port 52, 53 and a single band output port 54, 55, respectively. The COMSEP 30 of the first end node 12 which includes the C-band filter 34 couples to a COMSEP 42 in the repeater node 16 that includes an L-band transmissive filter 56. A COMSEP containing an L-band transmission filter may be generally referenced as an "L-band COMSEP" in later portions of the document. As will be discussed, the alternating arrangement of single-band C-band and L-band filters within the COMSEP units of each subsequent node provides advantages with regard to reduction of insertion loss for filters.

As would be understood by those skilled in the art, depending on the distance between the two end nodes, a given number of repeaters may be located between the first end node 12 and the second end node 14. The second end node 14 is essentially a complementary image of the first end node. That is, whereas the COMSEP 30 of the first end node 12 includes a C-band transmission filter 34, the COMSEP 60 of the second end node 14 includes an L-band transmission filter 62. Similarly, the optical amplifiers, multiplexers, demultiplexers and optical translator units are all adapted to the alternate band wavelengths. The second end node 14 couples to the bi-directional fiber 18 through the bi-directional input/output port 64 of the L-band COMSEP 60. The single band

output port 68 of the L-band COMSEP 60 in the second end node 14 couples to an optical amplifier 72 which then couples to an optical demultiplexer 74. C-band optical translator units 76 couple to the outputs of the optical demultiplexer 74 for translating the outputs of the optical demultiplexer back to their nominal 1310 nm wavelength.

On the input side of the second end node, optical translator units (OTUs) 78 are included for converting incoming wavelengths to an appropriate wavelength in the L-band. As shown, the OTUs couple to an optical multiplexer 80 and an optical amplifier 82. The optical amplifier 82 couples to the single band input port 70 of the L-band COMSEP 60 of the second end node 14.

Having described the basic structure of the bi-directional transmission system 10, the operation of the present invention can now be described greater detail. Beginning with the first end node 12, incoming wavelengths, e.g., 1310 nm, enter the optical translator units 20 (OTUs) and are translated to an appropriate wavelength in the C-band (e.g., in the range of 1530nm to 1563nm). These C-band signals are spectrally combined in the optical multiplexer 22 and then amplified via the optical amplifier 24. The C-band signals are sent to a C-band transmission optical filter 34 at the single band input port 26 in the COMSEP 30. The filter transmits these C-band signals to the bi-directional port with a low insertion loss. With regard to the C-band COMSEP 30, filters are available today with 1.7 dB insertion loss for the worst case under all operating conditions and with 1.3 dB for typical performance at the exemplary target frequencies specified herein. The loss is calculated based on a 1.5 dB transmission loss and an approximate 0.2 dB loss for two connectors. Filters having the above characteristics are available from suppliers such as JDS Uniphase of San Jose, California and E-TEK Dynamics, Inc. of San Jose, California.

The C-band signals propagate from the first end node 12 to an intermediate node 16 on this common fiber 18. Some portion of the C-band signal may change direction in the common fiber due to a variety of causes including imperfect splices, poor connectors, or even non-linear fiber properties. However, most of these reflected C-band signals that happen to change direction and return to the first end node 12 will be routed by the C-band filter 34 of the COMSEP 30 from the bi-directional port 32 to the single band input port 26. A minimal signal level will be transmitted from the bi-directional port to the output port 28 as determined by the performance of the optical filter used. For example,

the suggested filter components will deliver -15dB or better performance worst case for this parameter. When combined with the worst case spectral performance of the optical amplifier 36 and demultiplexer 38, those skilled in the art would see that no additional spectral filtering is needed for reasonable levels of reflected C-band signals.

5 At the repeater node 16, the C-band signals from the first end node 12 enter the L-band COMSEP 42 through its bi-directional port 50. This COMSEP 42 has an L-transmission filter 56 and therefore, as shown, the C-band signals reflect off the L-band filter to the output port 52 with minimal insertion loss. L-band filters for this application are available with 0.9dB for the worst case insertion loss under all operating conditions
10 and with 0.3-0.5dB typical performance. The loss is calculated based on a 0.7 dB transmission loss and an approximate 0.2 dB loss for two connectors. The C-band signals are amplified in the optical amplifier 46 and then directed to the input port 53 of the C-band COMSEP 44. The C-band signals are propagated from this repeater node 16 to the next node in the system in this manner.

15 C-band signals exiting the output port of a C-band COMSEP in a last repeater node enter an L-band COMSEP 60 in the second end node 14 through its bi-directional port 64. As shown, the C-band signals reflect off this filter 62 to the output port 68, again with minimal insertion loss. The COMSEP 60 is coupled to an optical amplifier 72, which is in turn coupled to a demultiplexer (DEMUX Cn) 74. The C-band signals are
20 amplified in the optical amplifier 72 and then spectrally separated in the demultiplexer 74. The C-band signals are then spectrally converted back to a nominal wavelength (typically 1310nm) utilizing the OTU units 76 (cn1 through cnx).

In a similar manner to the C-band signals, nominal wavelength input signals (typically 1310 nm) entering the L-band OTUs 78 in the second end node 14 are
25 translated to appropriate L-band wavelengths (typically in the range of 1573nm to 1610nm). The signals are then propagated from the second end node 14 to the first end node 12 in a similar manner to that described with respect to the C-band signals. At the first end node 12 the L-band signals reflect off of the C-band filter 34 in the COMSEP 30. The L-band signals are amplified in the optical amplifier 36 and then spectrally
30 separated in the demultiplexer 38 (DEMUX L1). The L-band signals are then spectrally

converted back to a nominal wavelength (typically 1310nm) utilizing the OTU units 40 (111 through 11x).

The alternating use of C and L transmission filters as described with respect to present invention provides several important advantages to the overall system. The most
 5 apparent is that bi-directional transmission on the single fiber between the nodes is realized. This reduces the required fiber to make a two way connection between two network elements by half compared to the current practice in many systems. Understandably, this is a very significant cost saving for customers.

Use of the alternating arrangement of the filters as shown in accordance with the
 10 present invention also results in a minimum optical insertion loss at the point of the separation of the low level input signal at each node. This is true for both directions of transmission and is a direct consequence of alternating the filters as described. As can be seen from the Fig. 1, C-band signals traveling from the first end node 12 to the second end node 14 are always separated using a reflection path in an L-band COMSEP.
 15 Similarly, L-band signals traveling from the second end node 14 to the first end node 12 are always separated using a reflection path in a C-band COMSEP. Minimizing insertion loss at the point of separation of the bands is critically important because any extra insertion loss at this point is difficult to recover in the system level optical power budgets. This difficulty arises today in real systems because the high power levels that are used for
 20 the optical signals launched into the fiber 18 give rise to many corrupting undesirable non-linear effects in the optical fiber between the nodes of the systems. Therefore, the signal launch power levels into fiber 18 are limited and cannot be increased to make up for additional separation loss.

The alternating arrangement of the filters as shown also enables the insertion loss
 25 at the launch side filter to be recovered by having a higher power optical amplifier output without incurring non-linear optical power penalties in the outside fiber plant. This is possible because the fiber lengths used between the output of the optical amplifier and the input of the COMSEP are short and, therefore, the optical power penalties due to the higher power until the loss of the COMSEP is encountered are quite negligible.

30 The system optical power budget is a critical parameter in determining the maximum distance between the optical translator units as it has a direct bearing on the

realized system optical signal to noise ratio. In typical systems, a reduction by one half of the noise contribution per span (-3 dB) can be utilized to double the number of spans (+3 dB) before an optical translator unit must be used to regenerate the signal. A system in accordance with the present invention has a 0.8 dB to 4 dB advantage for the optical power budget over the equivalent unidirectional system. This advantage is a function of the specific limitation that a unidirectional system encounters and can be used to either increase the permitted span loss or to increase the maximum number of spans between regeneration of the signals.

The use of only two (2) bands is required to achieve this minimal separation loss. Hence, each band must be wide to support a maximum number of channels. Practical systems today offer channels covering 3-4 THz of spectrum in each band. The selection of wavelengths used here is driven, for example, by available technology for amplification components and by fiber transmission loss characteristics which give minimum fiber loss at about 1565nm. Hence, the loss in the two bands is approximately equal for the fiber between the nodes of the system. Although the present invention is illustrated for use with wavelengths in the C-band and L-band, it would be understood that the present invention is not so limited and that other bands of wavelengths may also be utilized, for example, more bands may soon be practical between 1300 nm and 1530 nm ("S" band) on fiber in which the water loss peak has been removed. Such bands would have desirable optical dispersion characteristics for channels without having too high a loss characteristic and would be tolerant of higher launch powers compared to present non-zero dispersion shifted fibers. As would be understood, optical characteristics of the single direction optical components would need to be modified accordingly.

Another advantage of the present invention is that the L and C-bands are typically separated by approximately 11nm of optical bandwidth. The use of these separated wide bands means that stimulated Brillouin scattering (which occurs with a small wavelength offset and counter propagates to the original signal direction) will not cause any penalty. This is due to the directional characteristic of the optical filters in the COMSEP units and is a characteristic not achieved using other means of signal direction such as optical circulators. In this way, the bands are well isolated from one another.

The use of the low loss single band reflection filters shown in the figure is also accompanied by appropriate design of the individual band components, e.g., optical amplifiers, multiplexers and demultiplexers, to assure that any non-ideal leakage of the other band signals do not cause degradation to desired band signals. For instance,

5 selection of the optical amplifiers may include optimized rejection of oppositely directed alternate band signals. In general, however, the individual band components, e.g., optical amplifiers, multiplexers and demultiplexers, selected for use with the present invention are commonly available components, the source of which would be understood to a person skilled in the art.

10 The present invention is additionally advantageous in that having the signals in the bands travel in opposite directions improves the overall system performance as the interactions of the signals in the two bands is reduced by the fast transit time of one signal with respect to another. This minimizes the system margin that must be allocated for some types of non-linear signal corruption, for example, noise in optical receivers

15 caused by raman coupling between optical signals.

In addition, the total optical power at any connection in the system is reduced compared to equivalent unidirectional propagation by approximately a factor of (2) two. This allows the system to realize higher performance before various hazard levels are crossed. For example, systems that have cross-sectional power levels exceeding 50 mW

20 (approximately +17dBm) in the 1500 – 1650 nm range must utilize automatic power shutdown methods to maintain a hazard level 3A rating. As the optical power is increased, the time allowed for shutdown to complete is reduced proportionally. Thus, the present invention permits a shutdown time of nearly double the prior art for the same system total launch power in the two bands. This reduces the required design effort in

25 other sub-systems. In addition, there are physical considerations for fiber where an event (opening a fiber connection for example) triggers a destruction of the fiber ends or can even destroy the fiber all the way back to the amplifier (source of the optical power). Some of these destructive efforts are found at power levels that practical systems employ. Others occur at levels yet to be achieved for commercial systems. The present invention

30 allows operation to just below the threshold for these effects for nearly a factor of two in total system power. This happens because half the power is launched from each end of

the fiber and this power is typically attenuated by 3 dB (half) in 10-15 km of fiber. As long as the fiber length between nodes exceeds twice this distance (and it does as systems are usually designed for 80 km node spacing), the peak power level in a cross-section of the fiber will not significantly exceed the power level launched into the fiber from one end alone.

The foregoing description merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements, which, although not explicitly described or shown herein, embody the principles of the invention, and are included within its spirit and scope. For instance, it will be appreciated that the use of the C-band and L-band in the illustration of the invention is merely exemplary and that the use of other bands and sub-bands is contemplated within the scope of the present invention. More specifically, other bands including the C/S bands, and other sub-bands including the C1/C2 sub-bands may also be utilized. Also, although the unidirectional components are represented as single components, it would be understood that more than one component may be utilized to achieve the desired functionality. Furthermore, all examples and conditional language recited are principally intended expressly to be only for instructive purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass both structural and functional equivalents thereof. Additionally, it is intended that such equivalents include both currently known equivalents as well as equivalents developed in the future, i.e., any elements developed that perform the same function, regardless of structure.

In the claims hereof any element expressed as a means for performing a specified function is intended to encompass any way of performing that function including, for example, a) a combination of circuit elements which performs that function or b) software in any form, including, therefore, firmware, microcode or the like, combined with appropriate circuitry for executing that software to perform the function. The invention as defined by such claims resides in the fact that the functionalities provided by

- the various recited means are combined and brought together in the manner which the claims call for. Applicant thus regards any means which can provide those functionalities as equivalent as those shown herein. Many other modifications and applications of the principles of the invention will be apparent to those skilled in the art and are
- 5 contemplated by the teachings herein. Accordingly, the scope of the invention is limited only by the claims appended hereto.

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What is claimed is:

1 1. A system for bi-directional transmission of optical signals over a single
2 optical medium coupled between at least two nodes, said system utilizing a first optical
3 transmission band for signals traveling in a first direction and a second optical
4 transmission band for signals traveling in a second direction, said system comprising:
5 at least a first combiner/separator unit at a first of said two nodes, said first
6 combiner/separator including an input port, an output port and a bi-directional
7 input/output port for coupling to said single optical medium, a first optical filter within
8 said first combiner/separator unit coupled to each of said ports therein, said optical filter
9 being substantially transmissive to optical signals of said first band entering said input
10 port and exiting on said bi-directional input/output port and said filter being substantially
11 reflective for signals of said second band entering said bi-directional input/output port
12 and exiting on said output port; and
13 at least a second combiner/separator unit at a second of said two nodes, said
14 second combiner/separator including an input port, an output port and a bi-directional
15 input/output port coupled to said optical medium, a second optical filter within said
16 second combiner/separator unit coupled to each of said ports therein of said second
17 combiner /separator unit, said second optical filter being substantially transmissive to
18 optical signals of said second band entering said input port and exiting on said bi-
19 directional input/output port and said filter being substantially reflective for signals of
20 said first band entering said bi-directional input output port and exiting on said single
21 direction output port.

1 2. The system of Claim 1, further including at least one intermediate node,
2 said intermediate node comprising:
3 at least one said first combiner/separator unit and at least one second
4 combiner/separator unit, and
5 at least a first and second optical amplifier, said output port of said first
6 combiner/separator unit coupled to said input port of said second combiner/separator unit
7 through said first optical amplifier, said output port of said second combiner/separator
8 unit coupled to said input port of said first combiner/separator unit through said second
9 optical amplifier;

10 said first and second combiner/seperator units being alternately coupled within
11 said bi-directional transmission system such that pairs of said first and second
12 combiner/seperator units are utilized in combination, said bi-directional ports of said
13 combiner/seperator units being coupled to one another.

1 3. The system of Claim 1, wherein said optical transmission bands are L-
2 band and C-band.

1 4. The system of Claim 1, wherein said first node includes a first set of one
2 or more optical translator units for translating received wavelengths to wavelengths of
3 said first transmission band, said optical translator units being coupled to an optical
4 multiplexer unit and said optical multiplexer unit being coupled to said input port of said
5 first combiner/seperator unit;

6 said output port of said first combiner/seperator unit couple to an optical
7 demultiplexer unit, said optical demultiplexer unit coupled to a second set of optical
8 translator units for translating wavelengths of said second transmission band to said
9 received wavelengths.

1 5. The system of Claim 4, wherein said first node further includes at least
2 one optical amplifier coupled between an output of said multiplexer and said input port of
3 said first combiner/seperator unit and at least one optical amplifier coupled between said
4 output port of said first combiner/seperator unit and an input of said demultiplexer.

1 6. The system of Claim 1, wherein said second node includes a first set of
2 one or more optical translator units for translating received wavelengths to wavelengths
3 of said second transmission band, said optical translator units being coupled to an optical
4 multiplexer unit and said optical multiplexer unit being coupled to said input port of said
5 second combiner/seperator unit;

6 said output port of said second combiner/seperator unit coupled to an optical
7 demultiplexer unit, said optical demultiplexer unit coupled to a second set of optical
8 translator units for translating wavelengths of said first transmission band to said received
9 wavelengths.

1 7. The system of Claim 6, wherein said second node further includes at least
2 one optical amplifier coupled between an output of said multiplexer and the input port of
3 said second combiner/seperator unit and at least one optical amplifier coupled between
4 said output port of said combiner/seperator unit and an input of said demultiplexer.

1 8. The system of Claim 1, wherein said filters included in each of said first
2 and second combiner/seperator units are thin film wide-band filters.

1 9. The system of Claim 3, wherein said C-band and L-band filters include a
2 transmissive insertion loss in the range of 1.3 to 1.7 dB and reflective insertion loss in the
3 rang of 0.3 to 0.9 dB.

1 10. The system of Claim 2, wherein said intermediate node includes co-
2 located end terminals.

1 11. The system of Claim 2, wherein said intermediate node includes optical
2 add/drop terminals.

1 12. A system for bi-directional transmission of optical signals over a single
2 optical fiber, said system including at least two nodes having said optical fiber coupled
3 therebetween, said system utilizing only two distinct optical transmission bands, a single
4 one of said bands for transmission of said optical signals in one of two directions, the
5 other of said bands for transmission of said optical signals in the opposite direction, said
6 system comprising:

7 at least a first and second combiner/seperator unit, at least one combiner/seperator
8 unit located at each of said two nodes, each said combiner/seperator unit including an
9 input port, an output port and a bi-directional input/output port for coupling to said single
10 optical fiber, an optical filter within said combiner/seperator units coupled to each of said
11 ports, each said combiner/seperator unit operable to direct optical signals entering said
12 input port through said filter to said bi-directional input/output port and to reflect optical
13 signals entering said bi-directional input/output port off of said filter to said output port;
14 said optical filter in said first combiner/seperator unit being substantially
15 transmissive to a first of said two bands and substantially reflective to optical signals in
16 said second band traveling in an opposite direction;

20 said first and second combiner/separator units being alternately coupled within
21 said bi-directional transmission system such that pairs of said first and second
22 combiner/separator units are utilized in combination, said bi-directional ports of said
23 combiner/separator units being coupled to one another.

3 at least one said first combiner/separator unit and at least one second
4 combiner/separator unit, and

1 14. The system of Claim 12, wherein an end node in said system includes
2 either a first or second combiner/separator unit, said end node further including a first set
3 of one or more optical translator units for translating received wavelengths to
4 wavelengths of one of said two distinct transmission bands, said optical translator units
5 being coupled to an optical multiplexer unit and said optical multiplexer unit being
6 coupled to said input port of said combiner/separator unit; and

7 said output port of said combiner/seperator unit coupled to an optical
8 demultiplexer unit, said optical demultiplexer unit coupled to a second set of optical
9 translator units for translating wavelengths of said other of said two transmission bands to
10 said received wavelengths.

1 15. The system of Claim 14, wherein said end node further includes at least
2 one optical amplifier coupled between an output of said multiplexer and the input port of
3 said combiner/separator unit and at least one optical amplifier coupled between said
4 output port of said combiner/separator unit and an input of said demultiplexer.

1 16. The system of Claim 12, wherein said filters included in each of said first
2 and second combiner/seperator units are thin film wide-band filters.

1 17. The system of Claim 16, wherein said C-band and L-band filters include a
2 transmissive insertion loss in the range of 1.3 to 1.7 dB and reflective insertion loss in the
3 rang of 0.3 to 0.9 dB.

1 18. The system of Claim 12, wherein said transmission bands are selected
2 from the group consisting of L-band/C-band, C-band/S-band, C1 band/C2 band and S-
3 band/L-band.

1 19. The system of Claim 12, wherein said intermediate node includes co-
2 located end terminals.

1 20. The system of Claim 12, wherein said intermediate node includes optical
2 add/drop terminals.

1 21. A method for bi-directional transmission of optical signals over a single
2 optical fiber coupled between two nodes, said method utilizing only two distinct optical
3 transmission bands, a single one of said bands for transmission of said optical signals in
4 one of two directions, the other of said bands for transmission of said optical signals in
5 the opposite direction, said method comprising:

6 providing at least a first and second combiner/seperator unit, at least one
7 combiner/seperator unit located at each of said two nodes, said combiner/seperator units
8 each including an input port, an output port and a bi-directional input/output port for
9 coupling to said single optical fiber, an optical filter within said combiner/seperator units
10 coupled to each of said ports, each of said combiner seperator units operable to direct
11 optical signals entering said input port through said filter to said bi-directional
12 input/output port and to reflect optical signals entering said bi-directional input/output
13 port off of said filter to said output port

14 said optical filter in said first combiner/seperator unit being substantially
15 transmissive to a first of said two bands and substantially reflective to optical signals in
16 said second band traveling in an opposite direction,

17 said filter in said second combiner/separator unit being substantially transmissive
18 to signals in said second band and substantially reflective for signals of said first band
19 traveling in an opposite direction; and

20 alternately coupling said first and second combiner/separator units within said bi-
21 directional transmission system such that pairs of said first and second
22 combiner/separator units are utilized in combination, said bi-directional ports of said
23 combiner/separator units being coupled to one another.

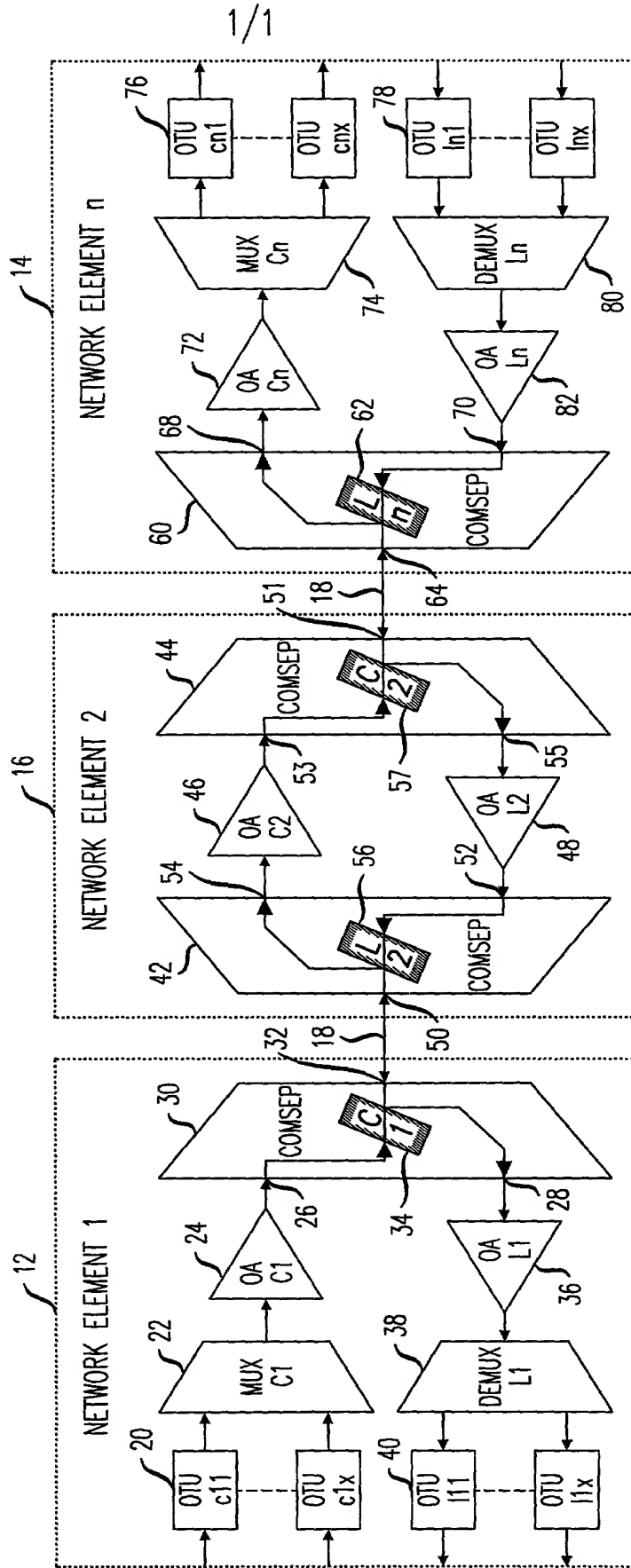
1 22. The method of Claim 19, wherein said transmission bands are selected
2 from the group consisting of: L-band/C-band, C-band/S-band, C1 band/C2 band and S-
3 band/L-band.

ABSTRACT

A bi-directional optical transmission system according to the present invention provides transport of x optical channels over n nodes. The system supports two-way transport of the x channels over a single fiber connecting each of the nodes in sequence. The system is advantageous in that only two optical transmission bands are utilized in order to achieve minimal loss in the separation of bands. The two directions of optical transmission on the fiber between the end nodes have a spectral (wavelength/frequency) separation, in addition to directional separation. The use of only two bands permits the utilization of low-loss wide band thin film optical filters to combine and separate the signals at each node. Further processing of the signals takes place in unidirectional components, e.g., multiplexers, demultiplexers and amplifiers, as required. An alternating arrangement of the optical filters in the two separate bands is chosen to maximize the optical performance of the overall system and significantly reduce insertion losses. In one exemplary embodiment of the present invention, at each intermediate node in the system a transmission filter for the first band of optical signals is used between the output of an optical amplifier for the first band and the bi-directional fibers. A reflection port of this filter is used to carry oppositely directed signals of the second band from the bi-directional fiber to an optical amplifier for the second band. An optical transmission filter for the second optical band is also used at each intermediate node between the output of an optical amplifier for the second band and the bi-directional fiber. The reflection port of the second band filter is used to carry the input signal of the first band from the bi-directional fibers to the optical amplifier for the first band. End nodes in the system include only an appropriate one of the transmission filters. The alternate arrangement of filters simultaneously provides for optimal signal performance for both directions of transmission at every node in the system while at the same time minimizing insertion losses from filtering components.

FIG. 1

10



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IN THE UNITED STATES
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Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and sole inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **Bi-directional Optical Transmission Using Dual Channel Bands** the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

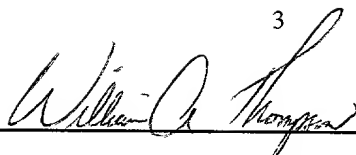
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